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Design and Analysis of Vortex Generator and Dimple over an Airfoil Surface to Improve Aircraft Performance

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Abstract: The main objective of the study is to enhance the aerodynamic characteristics and maneuverability of the aircraft which includes reduction in drag, increment in lift and delaying of flow separation and stalling. The research is primarily focused on increasing lift and reducing drag by introduction of dimple and vortex generator over an airfoil body. This paper also covers the basic designing of an airfoil with some surface modifications which results in higher lift to drag ratio, enhanced aerodynamic characteristics and efficiency of wing. Airfoil with dimple and vortex generator has been modeled and analyzed in ANSYS at various angles of attack. Computational results indicate that dimple makes aircraft wing more efficient by providing more lift to drag ratio than a vertex generator.

Keywords: Dimple, Vortex Generator, Airfoil, Lift, Drag, Flow Separation, Stalling, Boundary Layer

I. INTRODUCTION

Aerodynamic efficiency is one of the most significant parameters that determine performance, weight and cost of an aircraft. Aerodynamics is critical to both commercial and military aircraft as for commercial aircrafts, improved aerodynamic characteristics reduces operating costs. It significantly contributes to the national security by improving efficiency, maneuverability and performance of military aircraft. In aerodynamics, flow separation is an undesirable phenomenon and boundary layer control is an important technique for flow separation problems. Flow separation occurs when the boundary layer travels far enough against an adverse pressure gradient that the speed of the boundary layer relative to the airfoil falls almost to zero (Fig. 1).

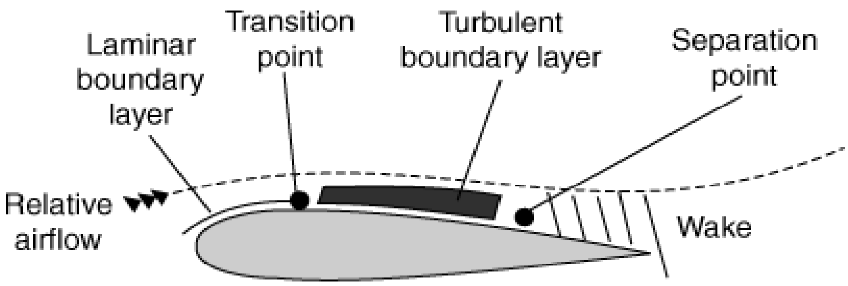

Fig. 1: Flow separations on airfoil

The fluid flow detaches from the surface and instead takes the forms of eddies and vortices. It can result in increased drag and stalling owing to significant loss in generated lift. By controlling the flow, the fuel consumption may be decreased to almost 30 percent as reported by Braslow (1999). In addition, lower fuel consumption will reduce the operating costs of commercial airplanes at least 8%.

Application of dimple on wing body is introduced which gives delay/advance transition, suppress/enhance turbulence or prevent/provoke separation, drag reduction, lift enhancement. It also increases the angle of stall by delaying the flow separation. Stalling is the strong phenomena during landing because at the time of landing aircraft high angle of attack leads to stalling of aircraft. This stall makes uncontrolled, leads to accident. To avoid this kind of situation we need to increase the stalling angle. Hence improved stalling characteristic is the best way to ease landing complexity. After passing the critical angle of attack, wing is unable to produce sufficient lift to balance weight, if this angle exceeds it leads to flow separation, thereby increase in drag, which reduces the L/D ratio. Modifying the aircraft wing structure by means of placing dimple will reduce the drag to considerable amount and helps to stabilize the aircraft during stall. For example, a golf ball with a dimpled surface can travel higher and further than a smooth surfaced golf ball when subjected to identical force. The dimples on golf balls induce turbulence at lower Reynolds number, providing extra momentum or energy to the boundary layer and causing delay in flow separation. This phenomenon causes smaller wake areas or swirling flow regions behind the ball, thus reducing the total drag. In deep, dimples delay the flow separation point by creating turbulent boundary layer by reenergizing potential energy in to kinetic energy.

Vortex Generator is most frequently used modifications to an aircraft surface to improve its maneuverability. It creates turbulence by creating vortices, which delays the boundary layer separation resulting in decrease of pressure drag and also increase in angle of stall. It helps to reduce the pressure drag at high angle of attack and also increases the overall lift of the aircraft. In this study we are designing two airfoils with surface modifications such as dimple and vortex generator with cylindrical profile and comparing them with simple airfoil. Aerodynamic analysis carried out using Computational Fluid Dynamics (CFD).

II. METHODOLOGY

To carry out the study on the proposed idea, standard airfoil profiles have been selected on which the whole study was conducted. Simulations were carried out on the airfoil – NACA 2412(Fig. 2). The study assumes the use of incompressible and isothermal flow.

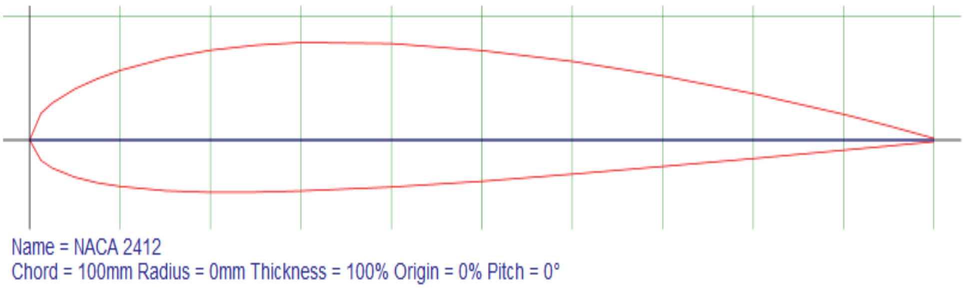

Fig. 2: NACA 2412 Profile.

A. Design Requirements

Selection of an airfoil for a wing begins with the clear statement of the flight requirements. For instance, a subsonic flight design requirement is very much different from a supersonic flight design objectives. On the other hand, flight in the transonic region requires a special airfoil that meets Mach divergence requirements. The designer must also consider other requirements such as airworthiness, structural, manufacturability, and cost requirements. In general, the following are the criteria to select an airfoil for a wing with a collection of design requirements:

1. The airfoil with the highest maximum lift coefficient.

2. The airfoil with the proper ideal or design lift coefficient.

3. The airfoil with the lowest minimum drag coefficient.

4. The airfoil with the highest lift-to-drag ratio.

5. The airfoil with the highest lift curve slope.

6. The airfoil with the lowest (closest to zero; negative or positive) pitching moment coefficient.

7. The proper stall quality in the stall region (the variation must be gentle, not sharp).

8. The airfoil must be structurally reinforceable. The airfoil should not that much thin that spars cannot be placed inside.

9. The airfoil must be such that the cross section is manufacturable.

10. Other design requirements must be considered. For instance, if the fuel tank has been designated to be places inside the wing inboard section, the airfoil must allow the sufficient space for this purpose

B. Airfoil geometry

Airfoil geometry is often summarized by a few parameters such as: maximum thickness, maximum camber, position of max thickness, position of max camber, and nose radius. The airfoil shape (Fig. 3) is obtained by combining the camber line and the thickness distribution in the following manner.

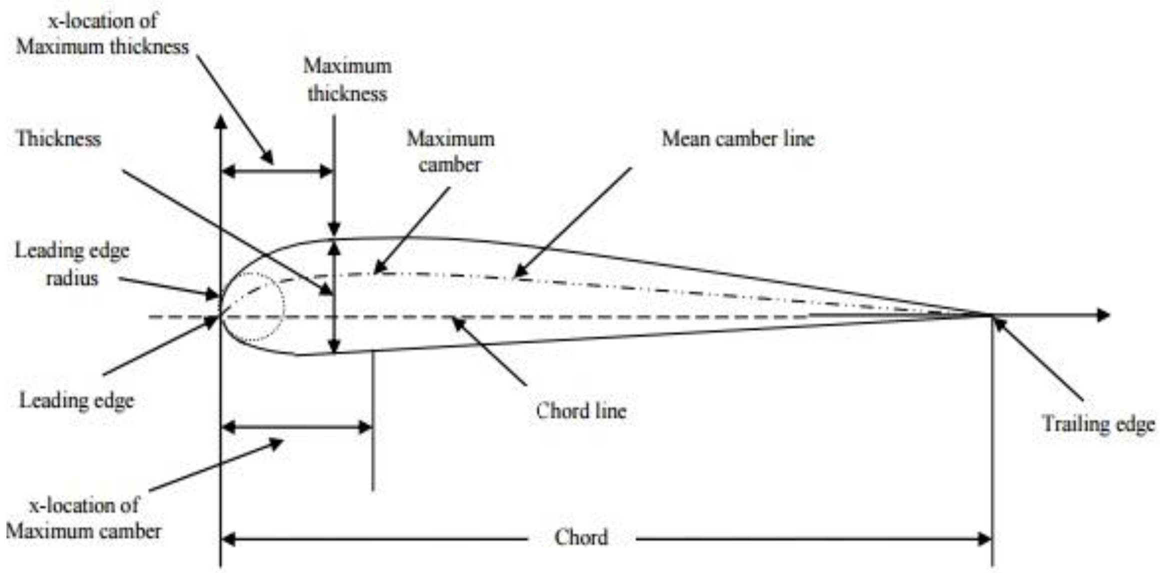

Fig. 3 Airfoil profile with various parameters

Draw the cord line and lines perpendicular to it at various locations (Fig. 4a). Lay off the thickness distribution along the lines drawn perpendicular to the mean line (Fig. 4b). The center of the leading edge radius is located along the tangent to the mean line at the leading edge (Fig. 4c). Depending on the thickness distribution, the trailing edge angle may be zero or have a finite value. In some cases, thickness may be non-zero at the trailing edge (Fig. 4d).

C. NACA 4 digit airfoil Design

The camber of a four-digit airfoil has made up of two parabolas. One parabola generates the camber geometry from the leading edge to the maximum camber, and another parabola produces the camber shape from the maximum camber to the trailing edge. This airfoil is controlled by 4 digits which designate the camber, position of the maximum camber and thickness. In NACA MPXX, M is the maximum camber divided by 100. P is the position of the maximum camber divided by 10. XX is the maximum thickness divided by 100. Following equations are used to calculate camber and gradient:

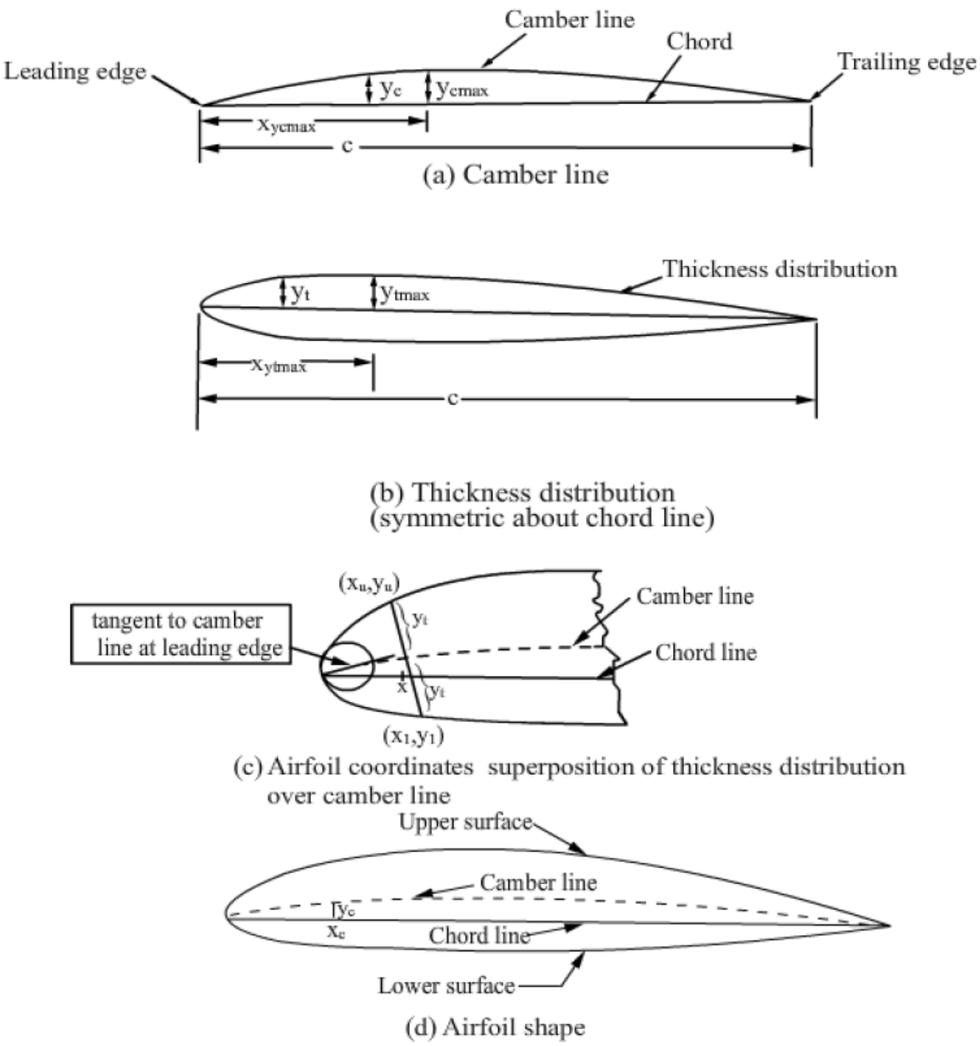

Fig. 4 Airfoil geometry

Front ($0 \le x < P$)

Camber, $Y_c = M(2Px - x^2)/P^2$ (1)

Gradient, $dy_c/dx = 2M(P-x)/P^2$ (2)

Back ($P \le x \le 1$)

Camber, $Y_c = M(1-2P+2Px-x^2)/(1-P)^2$ (3)

Gradient, $dy_c/dx = 2M(P-x)/(1-P)^2$ (4)

The thickness distribution is based on successful RAE & Gottigen airfoils. It is given as:

$y_t = 5T(a_0 x^{0.5} + a_1 x + a_2 x^2 + a_3 x^3 + a_4 x^4)$ (5)

Where:

$a_0 = 0.2969$ $a_1 = -0.126$ $a_2 = -0.3516$ $a_3 = 0.2843$

$a_4 = -0.1015$ or -0.1036 for closed trailing edge.

The constants a_0 to a_4 are for a 20% thick airfoil. The expression T/0.2 adjusts the constants to the required thickness. At the trailing edge (x=1) there is a finite thickness of 0.0021 chord width for a 20% airfoil. If a closed trailing edge is required the value of a_4 can be adjusted. The value of y_t is a half thickness and needs to be apply both sides of the camber line. Using the equations above, for a given value of x it is possible to calculate the camber line position Y_c, the gradient of the camber line and the thickness. The position of the upper and lower surface can then be calculated perpendicular to the camber line (Fig. 5)

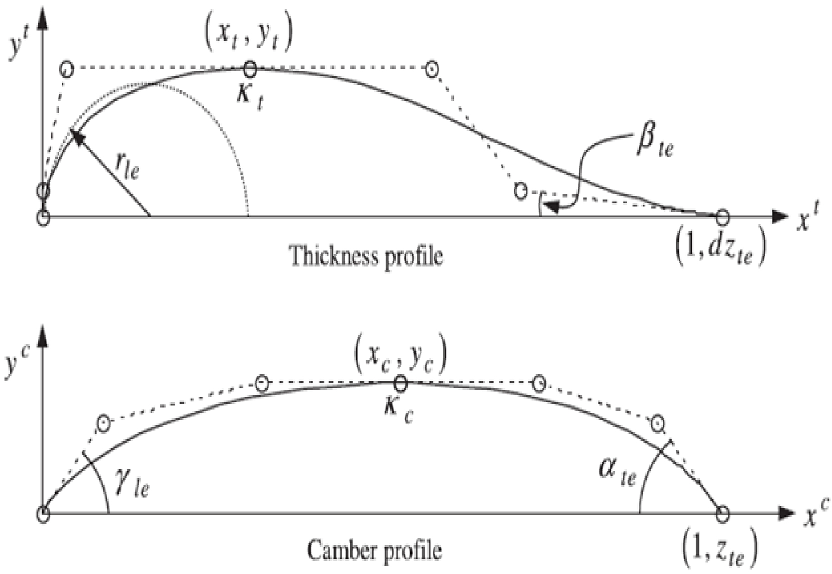

Fig. 5 Thickness and Camber profile

Upper surface,

$x_u = x_c – y_t \sin(\theta)$ (6)

$y_u = y_c + y_t \cos(\theta)$ (7)

Lower surface,

$x_l = x_c + y_t \sin(\theta)$ (8)

$y_l = y_c – y_t \cos(\theta)$ (9)

Here, $\theta = \text{atan}\,(dy_c/ dx)$

The most obvious way to plot the airfoil is to iterate through equally spaced values of x calculating the upper and lower surface coordinates. While this works, the points are more widely spaced around the leading edge where the curvature is greatest and flat sections can be seen on the plots. To group the points at the ends of the airfoil sections, cosine spacing is used with uniform increments of β.

$X = 0.2\,(1\text{-}\cos\beta)$ where: $0 \le \beta \le \pi$

D. NACA 5 digit airfoil Design

It was observed that maximum coefficient of lift of the airfoil could be increased by shifting forward the location of the maximum camber. This finding led to development of five-digit series airfoils. The new camber lines for the five-digit series airfoils are designated by three digits. The same thickness distribution was retained as that for NACA four-digit series airfoils. The camber of a five-digit airfoil section has made up of one parabola and one straight line. The parabola generates the camber geometry from the leading edge to the maximum camber, and then a straight line connects the end point the parabola to the trailing edge. In a five-digit NACA i.e., NACA LPQXX airfoil section the first digit represents the 2/3 of ideal lift coefficient in tenths. It is an approximate representation of maximum camber in percent chord. The second digit indicates the position of maximum camber in two hundredths of chord length. The last two digits represent the maximum thickness-to-chord ratio. A zero in the first digit means that this airfoil is a symmetrical airfoil section. The camber line shape is given as:

$y_c = (1/6)\, k_1\, [x^3 – 3mx^2 + m^2\,(3\text{-}m)\, x],\ 0 < x \le m$ (1.10)

$y_c = (1/6)\, k_1\, m^3\, [1\text{-}x],\ m < x < 1$ (1.11)

The value of ‘m’ decides the location of the maximum camber.

E. Shape, size and location of modification over an airfoil

Two types of shapes, a dimple and a vortex generator with cylindrical profile (Fig. 6 and Fig. 7 respectively) are considered to investigate the behavior of flow over airfoil body.

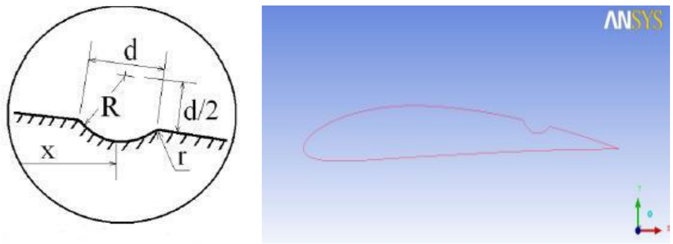

Fig. 6 Profile view of dimple over an airfoil

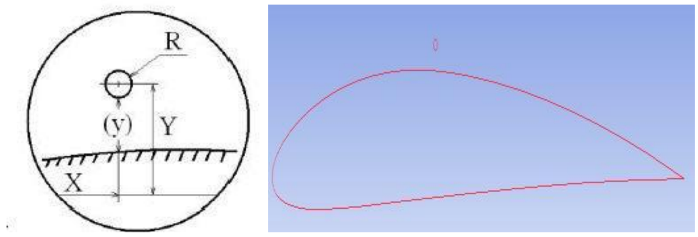

Fig. 7 Profile view of vortex generator over an airfoil

Table 1. Specifications of dimple

Dimple	x	d	R	r
	0.75c	0.05c	d	d/10

Table 2. Specifications of vortex generator

Vortex Generator	X	Y	y	R
	0.6c	0.077c	0.02c	0.005c

Adding an ununiformed shape on a streamlined body helps to delay the flow separation and reduce the size of the wake but it might also increase the friction drag as a trade-off. Hence, it is necessary to optimize the position and dimensions of the dimple relative to the size of the whole body. Table 1 represents size and location of a dimple on airfoil and table 2 represents X, Y and R arrangements of a cylindrical body placed over an airfoil, where (y) is the gap between the vortex generator and the airfoil.

III. RESULTS

Lift, drag and lift to drag ratio are investigated by adding the two different shapes in the flow over an airfoil body at various angle of attacks such as 0°, 5°, 10° and 15°. Table 3 and 4 represents differences in lift, drag and their ratios between a conventional airfoil which is without any modification and with airfoil modified with addition of a dimple and Vortex generator respectively. Clearly modified airfoil shows better results as compare to conventional airfoil. It is showing that C_l/C_d with dimple is 13, 4.6, 4.8 and 1.8 times more than and C_l/C_d with Vortex generator is 11.3, 3 and 3.51 more than of simple airfoil at 0°, 5°, 10° and 15° angle of attack respectively.

Table 3. Lift, drag and lift to drag ratio of simple airfoil and airfoil with dimple at various angle of attacks.

Angle of attacks	Simple airfoil			Modified airfoil		
	C_l	C_d	C_l/C_d	C_l	C_d	C_l/C_d
0°	6.93E-05	5.91E-05	1.17	3.80E-03	2.30E-04	16.51
5°	4.42E-04	8.30E-04	5.33	8.8E-3	2.95E-04	29.87
10°	6.78E-04	1.36E-04	4.98	1.28E-02	4.42E-04	28.89
15°	7.84E-04	2.24E-04	3.5	1.23E-02	1.28E-03	9.658

Table 4. Lift, drag and lift to drag ratio of simple airfoil and airfoil with Vortex generator at various angle of attack.

Angle of attacks	Simple airfoil			Modified airfoil		
	C_l	C_d	C_l/C_d	C_l	C_d	C_l/C_d
0°	6.93E-05	5.91E-05	1.17	3.9E-03	2.7E-04	14.44
5°	4.42E-04	8.30E-04	5.33	7.5E-03	3.5E-04	21.43
10°	6.78E-04	1.36E-04	4.98	1.1E-02	4.9E-04	22.45

IV. CONCLUSION

Modification of aircraft surface with vortex generator clearly gives more lift but it also increases the drag as induced vortices. It delays flow separation and stalling but also increase fuel consumption. On the other hand dimple gives more lift coefficient and less drag coefficient than vortex generator and results shows clearly that C_l/C_d is much more in case of dimple. Hence, Overall performance of an aircraft will increase if the airfoil surface is modified by dimple than vortex generator.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical statement: The authors declare that they have followed ethical responsibilities

REFERENCE

[1] Bogdanovic-Jovanovic, B. Jasmina Zivojin M. Stamenkovic and Milos M. Kocic, 2012 "Experimental and Numerical Investigation of flow around a sphere with dimples for various flow regimes," Thermal Science, Vol.16, No.4, pp.1013-102.

[2] Channu Raju and P.R. Viswananth, 2001 "Base Drag Reduction Caused by Riblets on a GAW aerofoil", Journal of Aircraft Vol.No.6: Engineering Notes. .

[3] Deepenshu Srivastav, (2012), "Flow Control Over Aerofoils Using Different Shaped Dimples", International Conference on Fluid Dynamics and Thermodynamics Technologies (FDTT) IPCSIT Vol.33 IACSIT Press, Singapore.

[4] Livya E, Anitha G, Valli P, Aerodynamic Analysis of Dimple Effect on Aircraft Wing,World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial, Mechatronics and Manufacturing Engineering, Vol.9, No.2,2015.

[5] Saarang S. Mahamuni, A Review on study of Aerodynamic Characteristics of Dimple Effect on Wing, International Journal of Aerospace and Mechanical Engineering, Vol.2, No.4, July 2015.

[6] Mohanasaravanan P S,Flow analysis around the dimple wing on aircraft,International Journal of Engineering Research Online, A peer Reviewed International Journal, Vol.3, No.2,2015

[7] Bhadri Rajasai, Ravi Tej, Sindhu Srinath, Aerodynamic effect of Dimple on Aircraft Wings,Proc. of The Fourth Intl. Conf. On Advances in Mechanical, Aeronautical and Prouction Techniques - MAPT 2015.

[8] Choi KS.Effect of longitudinal pressure gradient on turbulent drag reduction with riblets. In: Coustols E, editor. Turbulence control by passive means. Dordrecht, Netherlands: Kluwer Academic, 1990.

[9] John D. Anderson; "Fundamental of Aerodynamics", third edition. Frank K. Lu and Adam J. Pierce, January 2011 "Review of Micro Vortex Generators in High Speed flow", 49th AIAA Aerospace Sciences meeting including the New Horizons forum and Aerospace Exposition

[10] STORMS, B.L., "Lift enhancement of an aerofoil using a gurney flaps and vortex generators", J Aircr, 1994, 31, (3), PP 542-547.

[11] Sorensen, N. N., Zahle, F., & Bak, C. (2014). Prediction of the Effect of Vortex Generators on Airfoil Performance. Journal of Physics: Con-ference Series 524. 524, pp. 1-11. Denmark: IOP Publishing.

[12] Patacsil, M. B. (2010). Dimples on Wing. California: California State Science Fair.

